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PALISADES, NEW YORK

Final Report

Natural Radiocarbon 14 Measurement and Application

Contract No. AF19[122]-214

Lamont Geological Observatory
(Columbia University)
Palisades, N. Y.

Final Report under Contract No. AF19(122)-214
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Natural Radiocarbon 14 Measurement and Application

Submitted by

J. Laurence Kulp, Ph. D.
Project Director
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Summary

This is a final report on Contract AF19(122)-214. As such it states the objectives, summarizes the results, and points out the fruitful avenues of research that have opened up as a result of the work on AF19(122)-214. The personnel that have been associated with the project are listed. Emphasis is placed on the academic and technical training which this contract has provided for these numerous graduate students. A financial statement is included summarizing the expenditures and comparing them with the budget. The publications that have resulted from work on this contract are listed with brief abstracts of their contents. It was considered unnecessary to repeat the details of these researches in this report since they are readily available in the scientific literature.

The important results of this project may be condensed as follows: A low-level counting laboratory which can routinely count natural concentration of Carbon 14 and other isotopes, was assembled. Studies in technique considerably advanced the experimental knowledge in this field during the course of the contract. These advances included extension of the range of the C^{14} dating method to 30,000 years, the use of samples as small as 0.5 g. of carbon, improvement in the stability, sensitivity and simplicity of the counter and improvement of shielding. A survey of the C^{14} content of CO_2 taken from a wide variety of atmospheric situations showed that it is constant to within 10% and possibly within 5%. The samples should be remeasured as greater precision is available. Various sources of modern carbon were assayed, including wood, shell, ocean water, air, and meat. The most unexpected thing about this was the similar concentration of C^{14} in the wood

and shell, indicating a contamination of ocean carbonate with "old" carbon. Samples of wood, peat, muck, and ocean bottom sediments have helped define the chronology of the last glacial phase which in turn is related to climatic change. Carbonate from ocean water shows age differences from the surface to the bottom, indicating the possibility of following climatic change in time by the temperatures of ocean bottom water. Finally the organic samples from the upper layer of T-3 ice island indicate that these islands are not "fossils" from the earlier part of the Wisconsin glaciation but apparently have formed more recently, possibly since the climatic optimum, about 4,000 years ago.

It is concluded that the work done achieved the specific objectives of this contract, and that the existence of the contract produced scientific ideas which will be productive for some years to come.

Statement of Objectives

The project as originally conceived had the following objectives:

(1) Develop the technique of very low-level beta counting for atmospheric research. This was to involve not only setting up equipment for specific measurements, but also a continuing study of the technique adopted as well as potential new methods.

(2) Study of the distribution of the Carbon 14 content of the atmosphere as a function of latitude, altitude, and land-sea area.

(3) Determine the time factor in major climatic changes in the past by C^{14} analysis of (a) carbonate sediments on the Atlantic Ocean floor, (b) ice samples from glaciers and continental ice sheets, (c) organic remains in such ice, and, (d) deep ocean water.

The first part of objective (1) was completed in late 1951. Development of the method and study of other methods continued with fruitful results until the conclusion of the project. The third objective was very important to the understanding of climatic change but was not pushed during the latter part of the project. In fact the only effort under this objective consisted of a few measurements of samples from T-3. After the project reorientation in mid-1952, almost all of the effort was placed on objective (2).

Essentially all of the objectives were achieved during the course of the project, although in each case more work could be done, i.e., the technique development is never really finished, the study of the distribution of atmospheric C^{14} could be continued with increasing refinement, and the use of C^{14} in determining the time of climatic change could be pursued about indefinitely. However, in each of these cases enough was done to satisfy the primary purpose for which the contract was written.

Personnel and Administration

During the course of this contract about fifteen different people have been employed. Eight of these were graduate students. Among these, seven have completed the M.S. degree and two the Ph.D. degree. Thus, in terms of training future scientists the project has been very fruitful. The men concerned were as follows:

W. Broecker	M.S. (1954)
D.R. Carr	M.S., Ph.D. (1954)
W. Eckelmann	M.S., expects Ph.D. 1955
H. Feely	M.S., Ph.D. (1954)
S.O. Harris	candidate for M.S.
H.J. Holland	M.S.
W. Snell	M.S.
L. Tryon	M.S.

The other people employed on the contract were project director, (summer only), technicians and part-time office help.

Financial Statement

The total amount authorized for this contract was $73,560. This has been completely expended as follows:

Salaries and wages	$21,563.
Allowance for indirect cost	9,921.
Equipment, materials and services	39,362.
Communication and shipping	737.
Travel	1,630.
Insurance	89.
Other expenditures (incl. Soc.Sec.)	258.
	$73,560.

With the exception of a somewhat higher ratio of equipment, materials and services to salaries and wages, the various items follow closely that predicted on the annual budgets.

Request has been made to have unexpended capital equipment transferred to Project AF19(604)-851.

Publications

The following publications resulted either directly from work on this contract or from work related in some way to the contract. Most of the age determinations of archeological materials, for example, were not part of this research program but were made possible by the developments in technique

resulting from research under AF19(122)-214. Under each publication is a copy of the abstract of the paper.

Kulp, J.L., Feely, H.W., and Tryon, L.E.; Lamont Natural Radiocarbon Measurements: No. I, Sci., Vol. 114, No. 2970, pp. 565-568 (Nov. 30, 1951)

Abstract: This is the first in a series of articles reporting the experimental results on the measurement of the Carbon 14 content of natural materials. Several dozen calibration measurements on samples of known age are reported as well as two dozen unknown. The results are consistent and show the possibility of precise dating back to 25,000 years ago.

Kulp, J.L., Tryon, L.E., and Feely, H.W., Techniques of Natural Carbon-14 Determinations; Trans. Amer. Geophys. Union, Vol. 33, No. 2, pp. 183-192 (April 1952).

Abstract: The techniques which are in use at the Lamont Geological Observatory for the preparation and counting of the Carbon-14 in natural carbon-bearing samples are described in detail. The first phase of the process includes preparation of pure carbon dioxide by burning or hydrolysis, the reduction to carbon with hot magnesium, and the extraction of the product to remove all substances except the carbon. The yield is generally 90 pct. of the carbon in the original sample with an ash content of about one per cent.

The carbon samples are mounted in a stainless-steel cylinder and counted against a background cylinder of stainless steel in a modified Libby screen-wall-type counter with an active counting length of eight inches and a diameter of three inches. This counter is surrounded with 30-by 2-inch cosmic-ray counters which are used in anticoincidence. The entire assembly is placed in a large shield with eight-inch thick iron walls. The electronic unit contains two regulated high-voltage supplies, drag-in voltage, monitor selector switch, anticoincidence analyzer, scale of four, and register.

This arrangement has provided background as low as 2.5 counts per minute with normal operation ranging from four to six counts per minute. The efficiency of the screen-wall counter is about five per cent. With three days of counting, this arrangement can measure samples up to 25,000 years old for wood and 30,000 years for shells. Application of this quantitative method of age determination to a wide variety of samples of geological interest is in process.

Kulp, J.L. and Tryon, L.E.; Extension of C-14 Age Method, Rev.Sci. Instr., vol. 23, No. 6, pp. 296-297 (June 1952).

Abstract: The use of a 1-in. mercury shield around the screen wall counter inside the anticoincidence ring of cosmic-ray counters makes it possible to reduce the background from 5 cpm to 2 cpm for an active counting volume 8 in. in length and 2-5/8 in. in diameter. This makes it possible to extend routine C-14 age measurements from about 25,000 to 30,000 years.

Kulp, J.L., Tryon, L.E., Eckelmann, W.R., and Snell, William A.; Lamont Natural Radiocarbon Measurements: II, Science, vol. 116, no. 3016, pp. 409-414, (Oct. 17, 1952).

Abstract: The measurements presented in this paper were made between November 1, 1951, and August 1, 1952. The recent advance in technique at the Lamont Observatory permits dating back to 30,000 years - an extension of 5,000 years over the period determinable with the technique available when the first list of dates from this laboratory was published. Included in this paper are about 80 new measurements of the Carbon-14 content of shells, wood, charcoal, peat, air, water, of significance to archeology, geology, and oceanography.

Kulp, J.L.; The Carbon 14 Method of Age Determination, Sci. Monthly, vol. LXXV, no. 5, pp. 259-267 (Nov. 1952).

Abstract: A review article bringing together the knowledge concerning the Carbon 14 method of age determination as of the summer of 1952. The article is fully illustrated showing techniques of measurement and methods of taking samples.

Kulp, J.L.; Carbon 14 Measurements on Geologic Samples, Atomics, vol. 4, (April, 1953).

Abstract: A summary of some of the most important measurements of C^{14} in natural materials to the winter of 1952-53. In particular the application of C^{14} dating to rate of rise of sea level since the last glaciation and the origin of petroleum are discussed. Important potential developments in technique suggest that organic silt or muck may be used for dating purposes and that liquid scintillation counting may greatly extend the range of the method.

Kulp, J.L., and Volchok, H.L.; Constancy of Cosmic Ray Flux Over the Past 30,000 Years, Phys. Rev., vol 30, no. 4, pp. 713-714 (May 15, 1953).

Abstract: The Carbon 14 method of age determination which has been used to date archeological and geological samples is based on two major assumptions: (1) The integrated cosmic ray flux is constant. (2) The C^{14} atoms produced in the upper atmosphere by the N^{14}.

(n, p)C^{14} reaction are rapidly mixed into the carbon reservoir of the atmosphere, biosphere, and hydrosphere. The time scale for these assumptions is on the order of centuries, since the average life of C^{14} atoms is approximately 8,000 years, and the present maximum C^{14} dating accuracy is ± 100 years.

The second assumption has been verified by the observation that the concentration of C^{14} in living organisms at widely different latitudes and in the carbon dioxide of the air at various locations and altitudes is essentially constant. The first assumption has been verified for the period of written history by showing that the Carbon 14 ages on archeological specimens are correct. Since this agreement was established for the last 4,000 years, and since the Carbon 14 atoms now found in modern wood are 8,000 years on the average, the integrated cosmic-ray flux seems to have been essentially constant for the last 12,000 years.

Unfortunately, this takes us back only to the end of the last great glacial period. A method was devised to show constancy from the present back to about the maximum of the last phase of the Wisconsin glaciation (estimated at 30,000-40,000 years ago). This span of recent earth history displays about one-half of the greatest mean annual temperature fluctuation since the Cambrian period (500,000,000 years ago). Thus if the cosmic-ray flux was constant in this interval, and if it is related in any way to the total energy received by the planet, the integrated cosmic-ray flux would appear to have remained constant over most of geologic time.

An attempt was made to determine the possible variation in the cosmic-ray flux by dating layers of mud in a deep sea core by both the Carbon 14 and ionium ($_{90}Th^{230}$) methods. For the ionium ages, the radium concentration in homogeneous cores as a function of depth was obtained. For the Carbon 14 ages, the carbon in the precipitated calcium carbonate of the same core was used.

Kulp, J.L.; Dating with Carbon 14, Journ. Chem. Educ., vol. 30, pp. 432-435 (Sept. 1953).

Abstract: One of the most important scientific discoveries of the past decade is the existence of measurable amounts of Carbon 14 in the atmosphere, hydrosphere, and biosphere by W.F. Libby and his associates. Since the half-life of Carbon 14 is reasonably long (5568 ± 30 years) and since a constant concentration is present in living things, air, and surface water, the time of removal from the carbon dioxide life cycle can be measured quantitatively if the Carbon 14 concentration is determined. Thus a method was devised which permits relatively precise age determination of archeological and geological materials from the present back to several tens of thousands of years ago. The time dimension is uniquely important to the sciences of archeology, anthropology, and geology, and as no

quantitative method was previously available for this time interval, the application of this method is causing a major advance in these sciences. At the present time some 400 dates have accumulated from work at Chicago and Columbia. Additional contributions from other laboratories are expected during the coming year. While a few anomalous results remain unsolved, the agreement between different laboratories, the self-consistency of the data, and the agreement of the ages measured with external checks provided by geology and archeology assure the general applicability of the method.
(Note: This is a general review article which covers the field up to June 1953)

Kulp, J. Laurence; Climatic Changes and Radioisotope Dating, Am. Acad. Arts and Sci., Symposium on Climatic Change, Edt. by Harlow Shapely, Chap. 16, pp. 201-208, (1953)

Kulp, J.Laurence, Radioisotope Dating of Climatic Change, Die Umschau (submitted for 1954 publication).

Abstract: Any examination of climatic change must be related to the time dimension. Whether we are concerned with short or long scale climatic changes, the origin of life, the early history of the planet, or the mechanism of climatic changes, it is imperative to know at what time events occurred. We must be able to follow the sequence in some quantitative fashion. Beyond written history, the significant quantitative methods involve radioactive isotopes and their products. Even within historical time, we must turn to radioisotopes to find out certain important climatological facts such as the rate of exchange of air masses between the hemisphere or the exchange of carbon between atmosphere and ocean.

All of the methods of radioactive dating are applicable to this problem but the most spectacular applications have been those due to Carbon 14 dating. Several examples of this application are given. The use of natural tritium may help solve many problems in the rate of climatic changes over the past decade in areas remote from civilization.

Kulp, J. Laurence and Carr, D.R., Dating with Natural Radioactive Carbon, Trans. of N.Y. Acad. of Sci., ser. II, vol. 16, no. 4 (Feb. 1954).

Abstract: This paper considers the problem of the possible variation in the various sources of modern carbon. The most important conclusion is that living shell and wood have about the same concentration of Carbon 14. This would not be predicted from the $C^{12}C^{13}$ ratios on similar materials. It is concluded that the ocean water carbonate is sufficiently contaminated with "old" carbonate that the C^{14} concentration is lowered.

Values are given for the average C^{14} concentration in sea water, air over land areas, meat associated with shells, shells, and wood.

Kulp, J. Laurence, The Carbon Clock, The Intelligence Digest Supplement, (June 1954).

(A popular article written at the request of the editor. The introductory statement by the editor follows).

The matter of time is of central importance to the sciences of geology, anthropology, and archeology, and it is a significant factor in many others, such as meteorology and oceanography. Whether one wishes to calculate the heat flow from the ocean floor, the rate of oil formation, or to define past epochs of mountain-building or ore deposition, it is necessary to know the absolute time of specific occurrences. This article tells you of the latest method of measuring the age of pretty well anything; whether it is a few hundred years old or many thousands. It is one of the most important scientific advances of the past ten years, and perhaps the greatest single advance ever made in historic science.

Kulp, J. Laurence, Ewing, M., and Iselin, Columbus O'D., Age of Deep Ocean Water, Geol. Soc. Amer. Bull. (Publication delayed).

Results

This summary of the results of this contract will follow the order of the statement of the objectives. The detailed information will be found in the Quarterly Progress Reports and the publications which have resulted from this project.

1. Develop laboratory for very low-level beta counting and study of techniques with regard to greater counting efficiency.

The establishment of the laboratory and the initial procedures and techniques were described in Progress Reports 1 and 2. The system and results attained at this stage essentially duplicated that developed by Libby.

Progress Report 3 describes a major improvement in the leaching procedure which reduced the ash content and the time of processing by subjecting the same to boiling nitric acid for ten minutes. Progress Reports 4 and 5 describe the reduction in background to 4.5 cpm by selecting the proper stainless steel for counter construction and using cosmic ray tubes 30" in length. These reports also describe the installation of a second complete counting system.

Progress Report 6 describes the major reduction in background to 2 cpm by the use of mercury shielding inside the anticoincidence ring. This permits extension of the C^{14} age method to 30,000 and increases the precision throughout the range of application of the method. The experiments leading up to this discovery are also described. Minor additional improvements in the carbon preparation and the counting technique were made during this period.

A new carbon counting technique using a CCl_4 slurry and a centrifugal spinner permitted the even mounting of samples as small as 0.5 gm. is described in Progress Report No. 7. Report No. 8 discusses the testing of some allegedly "infinite life" halogen filled cosmic ray counters made by the Anton Electronic Corp. Although these counters had good plateau characteristics, the efficiency was too low (35%) for anti-coincidence application. Later studies in cooperation with Anton raised this efficiency to 80-85%, but this is still inadequate. This report also contained a theoretical analysis of the possible methods of measuring Carbon 14 at natural levels with regard to efficiency, sensitivity, range and precision. It was concluded that liquid scintillation and gas proportional counting offer great promise, but the ionization chamber method probably

does not warrant extensive study.

In the period covered by Reports 9-11, a study of the background in all counters and electronic units over the past year was made. The background is generally characteristic of the counter and sample cylinder employed and was found to be independent of the electronic system. Atomic tests did not raise the general external background appreciably but affected the degree of carbon and sample cylinder contamination in an erratic manner. Spurious counts due to leakage along the glass insulators which shielded the center wire contributed appreciably to the background in the early stages of the project, but after these were replaced by teflon and polythene the problem was eliminated. The similar background obtained in the different shields, anticoincidence rings and electronic units pointed to radioactive isotopes in the materials of which the counters were made as the main source of the residual background. This was particularly striking in view of the differences in geometry of the A.C. rings and the type of shielding in the different units.

During the last year of the project it was desired to obtain higher precision on the C^{14} determination of the air samples so a comprehensive investigation of the causes of the minor variations was initiated. This study was divided into four parts, (a) contamination, (b) electronics, (c) counter characteristics, and (d) procedure.

Analysis of previous data showed that contamination occurred to the extent of 0.3 cpm during atomic tests. An air monitoring system was therefore set up and run daily. If the fission product concentration in the air

became greater than 10 X "normal" background, carbon samples were not leached nor mounted. In this way contamination from the air has been largely eliminated.

Variation in the efficiency of the ring of cosmic ray counters, particularly near the end of their life, has been a significant source of error. The problem was solved in two ways. First, the A.C. tubes were tested monthly for plateau length. Second, a modification was made on the electronic system to permit continuous mounting of the ring.

Other improvements included changing the procedure to minimum handling of the counters, the use of a hot C^{14} sample from Oak Ridge to study efficiencies as a function of geometry, time and filling gas pressure, and the reinsertion of the screen in a number of counters to improve the homogeneity of the field.

The net result of these improvements was to reduce the probable error in a single determination to less than 5% for a modern carbon sample. In the best cases it approaches 2%. It is desirable to reduce this further before the atmospheric samples are recounted. Work has started under Contract AF19(604)-851 on acetylene gas counting which will make possible a precision of 1% or better.

(2) Study of the distribution of C^{14} in the atmosphere.

Reconnaissance samples of CO_2 from city, country, and laboratory air were taken to prove the apparatus and to look for maximum variations. The city air had a slightly lower specific activity than the country air. The laboratory air being contaminated with gas burner CO_2 was much lower. These samples and results are described in Progress Reports 6 and 7.

Also included in Report No. 7 is a theoretical study of the quantity required for carbon dioxide from air, water and ice samples.

Progress Report No. 8 gives an account of the development of the apparatus and procedure for procuring carbon dioxide from air over land, over the ocean and at high altitudes.

Altogether about 20 samples have been taken over the land at the surface, about 8 over the land at altitudes ranging from 1,000 to 30,000', and about 3 over the ocean. The location and preliminary assay data on these samples can be found in Reports 9-12. Some of these were re-measured and were reported in Quarterly Progress Report No. 13, 14. Before the conclusion of the work for this contract, all of the surface samples were remeasured at least once. The final averaged counts are listed in Table I. Samples 165Q, 165T, and 165U still leave something to be desired by way of the precision of the runs; although with the technique then in use higher precision cannot be expected for samples smaller than 4.0 grams as is the case for 165T and 165U.

During the last quarter experiments were carried out in an attempt to determine what effect the oxidation of pump oil might have on the total CO_2 passing through the system. Unfortunately, the particular pump which was used in the land sampling during the summer of 1952 was no longer available, as it had later been sent to sea to take ocean samples and was badly corroded. A large pump with a faster rate of oil flow was available and was employed. This pump was run at various temperatures and rates of oil flow. The amount of CO_2 produced in processing an

equivalent quantity of air ranged from 2-20% of the carbon dioxide adsorbed. If this data is extrapolated to the smaller pump which runs at a lower temperature and a smaller quantity of oil, the contamination from this source should not exceed a few percent and in most runs should be negligible. It is of interest to note that the two largest runs at the highest temperatures were those at Needles, California (165Q) and at Vicksburg, Miss. (165U). However, if these two samples and the one extremely high value (165T) on a very small sample are omitted, the average remains essentially the same.

The average was obtained by weighting the sample counts by their deviations. The error placed on the final average is the average deviation considering the weighting factors.

Table 2 gives a corrected summary of the C^{14} concentration of all "modern" sources of carbon. This is the same as Table 5 in the Quarterly Report No. 15 with the exception of the air over land values.

The average wood count of 6.12±.06 should be equivalent to 15.3 dpm/grams of modern carbon according to Libby.

The following conclusions can be drawn from this data:

1. The C^{14} concentration of the atmosphere is constant to 10% and probably to 5% from 30,000' altitude to ground level.

2. This is true regardless of

   a. the time of day

   b. the time of year

   c. climate

d. plant cover

e. land or ocean areas

f. latitude or longitude

3. From the C^{12}/C^{13} data on similar materials it might have been expected that shells and sea water carbonate would be much higher (6%) in their C^{14} concentration than wood. That it is not, suggests the mixing of surface carbonate with "old" bottom water.

4. The lower value for meat over shell is expected from the C^{12}/C^{13} ratio data which is lower for meat.

5. That the average value for air is similar to wood is not unexpected.

6. To study the fine structure of possible variations in the C^{14} content of the atmosphere, refinements in the technique of measuring this quantity are required. The method of proportional counting of acetylene appears very promising in this regard and will be applied to additional atmospheric samples under AF19(604)-851.

7. These samples were all taken prior to the recent thermonuclear tests. It is possible that variations may be detected at long range due to such man-made phenomena.

8. The absence of appreciable variation in the C^{14} concentration of the atmosphere up to 30,000 feet proves the validity of one of the important assumptions used in C^{14} dating, i.e., the atmosphere is thoroughly mixed on the time scale of 100 years.

The third objective of this project was to determine the time factor in major climatic changes in the past. This was attempted by determining

the Carbon 14 concentration in a variety of materials. The results are described in the two papers published in Science entitled Lamont Natural Radiocarbon Measurements I and II by J. L. Kulp and others.

One area of study was that of carbonate sediments. The 105, 107, 121, and 153 series from North Atlantic cores showed that the rate of sedimentation in the ocean basin varies greatly and is complicated by turbidity current deposition, but layers of sediment on the ocean floor and consequently fossils, can be dated by C^{14}. The fossils in turn may be used to indicate the temperature of the surface water and hence the major climatic changes.

The cold bottom water of the North Atlantic Ocean at about latitude 55°N showed considerably less C^{14} than surface water, indicating that it had been separated from the atmosphere (surface) for something on the order of one thousand years. Climatic changes should affect the temperature of polar waters and thus show up as "pulses" in the temperature of the slow-moving bottom water. This opens up a whole new field of exploration in the large scale study of climate change. This interesting development is being followed up. Additional samples have been taken as support from other sources and an attempt to define the C^{14} concentration throughout the North Atlantic is being made.

The use of wood, peat, shell and other materials of organic origin in defining the rate of retreat of the last major glaciation has been quite successful. Some of the most important results in this category, which are reported in the publications noted above and from additional measurements in press, are as follows:

(1) The continental ice sheet was still below the Canadian border 11,500 years ago.

(2) The continental ice sheet finally melted away in the James Bay area of Canada only some 4-5,000 years ago.

(3) There have been a number of oscillations of climate in the last 10,000 years as are reflected in the readvance of ice in Alaska. Although some of these changes may be very local, there are others which appear more general, particularly at above 9,000, 4,000 and 500 years ago.

(4) The rise of sea level over the past 30,000 years after the maximum of the last major (Wisconsin) glaciation, appears to be fairly regular at the rate of about 100' per 10,000 years as is shown by samples measured from Bermuda and the Mississippi River delta region. Examination of the fine structure by more detailed samples at greater precision will undoubtedly show that the rise was not entirely linear. On the other hand, the linearity even with the present degree of crudeness in measurement might not have been expected and shows that on a world-wide basis the general change in planet temperature was fairly regular, although the process of adjustment of the atmosphere to this changing temperature caused irregular local variations.

(5) Samples from T-3 island included muck from several layers of ice and surface organic material. Unfortunately these samples were too small to give high precision with the existing methods of measurement (solid carbon-screen wall Geiger counters), so that it was only possible to prove that the top few feet of ice formed in less than a few thousand years. Additional larger samples have been procured, so that with the

new improved acetylene counting techniques a close definition of the rate of growth of the ice island will be possible.

It is in the area of the third objective that the largest amount of work remains to be done of considerable significance.

Future Possibilities

The worthwhile future research arising out of the work on AF19(122)-214 has been implicit in the foregoing discussion of the results but it would seem desirable to list some of the most significant problems and ideas that should be pursued. Some of these will be carried on under AF19(604)-851.

1. Development of proportional gas counting for larger and smaller samples. This will involve studies on the limitation of the acetylene counting and investigation of a simple high yield procedure of preparing ethane from acetylene with a view to high pressure counting for greater range and precision.

2. Development of liquid scintillation counting by the use of some compound such as benzene , where all of the carbon atoms in the liquid are sample atoms.

3. Repeat assay of the C^{14} concentration of the atmosphere as each major improvement in precision is attained. The repeat assay is required immediately since the acetylene counting has increased the precision from about 5% with the solid carbon method to 1%. Further sampling will also be necessary to complete this study.

4. The great value to marine geology, oceanography, and meteorology of the study of the C^{14} concentration in ocean bottom sediments has been demonstrated. This is probably one of the most important by-products of the research on this contract and will undoubtedly be the start of a continuing research program at a number of laboratories

5. The same statement may be made concerning the studies of the C^{14} in ocean water.

6. Organic material from glaciers and ice islands such as T-3 still presents some of the most interesting research related to the rate of climatic change. Some of this work will be continued under AF19(604)-1063.